Farm Energy IQ

Farms Today Securing Our Energy Future

Greenhouse Energy Efficiency (Heating)

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NORTHEAST SARE
Sustainable Agriculture Research & Education

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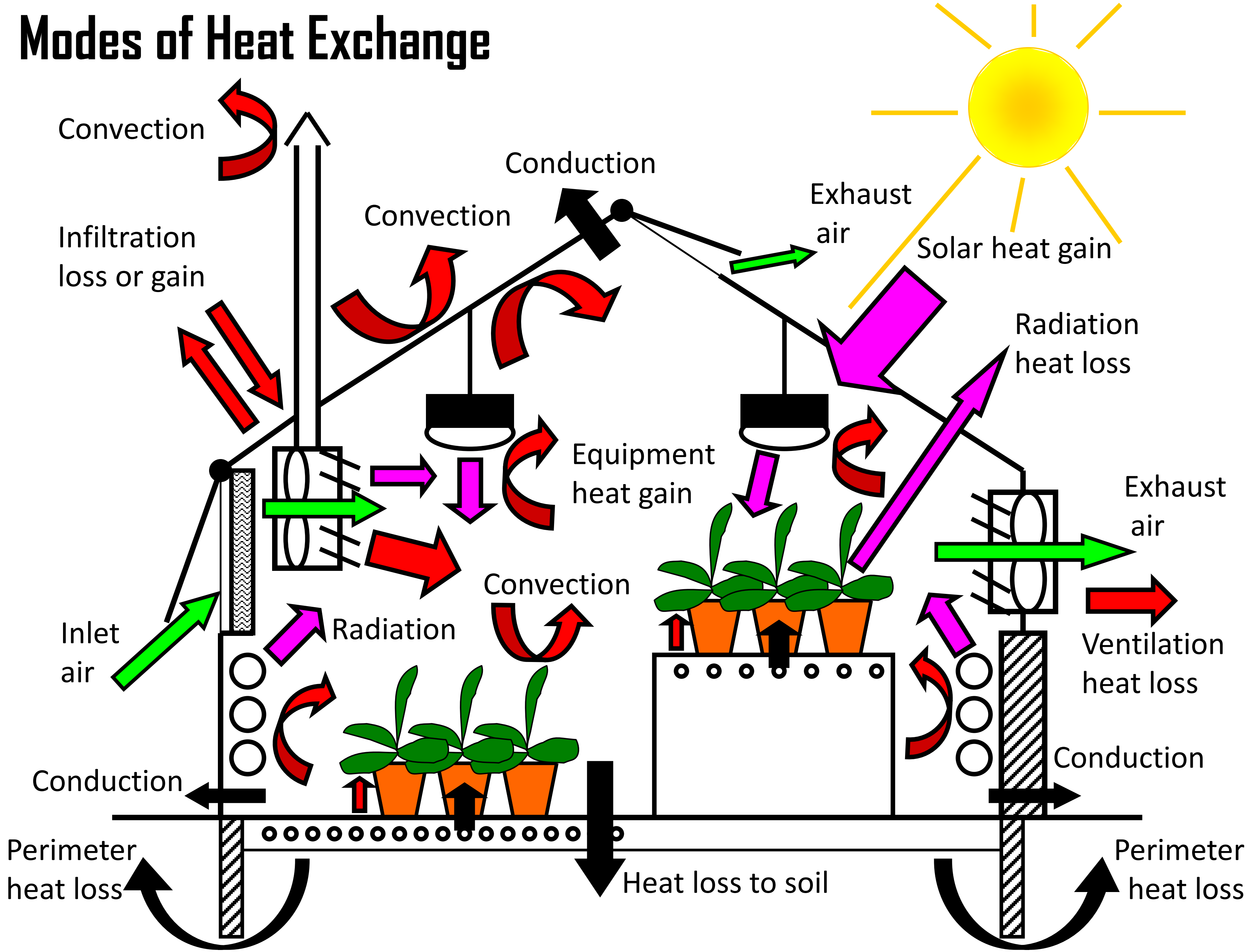
Presentation Outline

- After supplemental lighting (if used), temperature control (through heating and ventilation) typically consumes the most energy
- This presentation will focus on greenhouse heating:
  - Modes of heat exchange
  - Heat loss calculations (needed to check or design your own heating system)
  - Common heating system designs
  - Energy conservation (screens, storage) and control
  - Comparing energy prices
  - Energy saving measures
  - Summary

Modes of Heat Exchange



Greenhouse Heat Loss Calculations (Simplified)

- To size heating system (heater/boiler capacity), calculate:
  - Structural heat loss (conduction and convection)
  - Infiltration (air movement)
  - Perimeter heat loss (along outside walls)
- Make adjustments for high wind (over 15 mph) and/or large ΔT (over 70°F) if needed
- Total heat loss = sum of structural, infiltration, and perimeter heat loss (plus any adjustments needed)
- Overall equipment heating capacity must factor fuel conversion efficiency (so capacity > heat loss)

Structural Heat Loss

- Heat transfer through the structure depends on:
  - Heat transfer coefficient, U (U = 1/R)
  - Surface area, A
  - Temperature difference: $T_{inside} – T_{outside,\ 99\%}$ (ΔT)
- Equation:

$$Q = U \times A \times (T_{inside} - T_{outside,99\%})$$

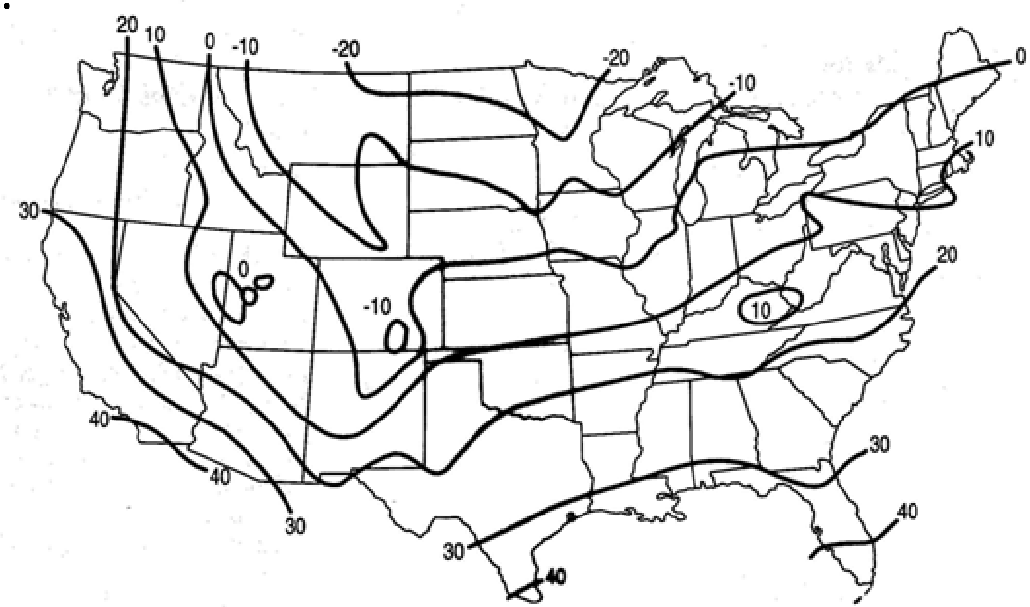
or

$$Q = UA\,\Delta T \qquad \text{[in Btu/hr]}$$

where: T_{inside} = nighttime temperature set point

Outdoor Design Temperature ($T_{outside,\ 99\%}$)

- For heating capacity calculations use the 99% outdoor design temperature $T_{outside,\ 99\%}$ (Engineering tables):
  - Burlington, VT: 11°F
  - Bangor, ME: -11°F
  - Concord, NH: -8°F
  - Albany, NY: 0°F
  - Worcester, MA: 0°F
  - Columbus, OH: 0°F
  - Pittsburgh, PA: 1°F
  - New Haven, CT: 3°F
  - Newark, NJ: 10°F
  - Atlanta, GA: 18°F
  - Portland, OR: 18°F
  - Tucson, AZ: 28°F
  - San Diego, CA: 43°F



Note: $T_{outside,\ 99\%}$ was determined for Dec., Jan., and Feb. i.e., 120 days or 2880 hours; 1% ≈ 29 hours, 1.2 days

U-Values
(higher U-value equates to more heat loss)

Material	U-value (Btu/hr per ft^2 per °F)*
Single (double) layer glass	1.1 (0.7)
Single (double) layer poly	1.1 (0.7)
Double layer + energy curtain	0.3 - 0.5
Double layer acrylic	0.6
Double layer polycarbonate	0.6
½-in. plywood	0.7
8-in. concrete block	0.5
2-in. polystyrene (R = 10)	0.1

*For sound, well sealed structures

Air Infiltration Heat Loss

Equation: $\boxed{Q = 0.02 \times V \times C \times (T_{inside} - T_{outside,\ 99\%})}$

where

V = greenhouse volume (ft^3)

C = number of air exchanges per hour (hr^{-1})

Type of construction	C*
New, glass	0.5 - 1.0
New, double poly	0.75 - 1.5
Old, glass and good condition	1.0 - 2.0
Old structure and poor condition	2.0 - 4.0

*a conservative approach is to take the largest value for C

Rollup Vent Louvers

Credit: http://www.northerntool.com/

If using standard louvers (as shown above), make sure they seal properly (even after extended use). Some designs are more durable than others.

Perimeter Heat Loss

Equation: $\boxed{Q = F \times P \times (T_{inside} - T_{outside,\ 99\%})}$

where

F = perimeter heat loss factor

P = greenhouse perimeter (in feet)

F	(Btu/hr per linear ft per °F)
Uninsulated	0.8
Insulated	0.4

When the water table is high (i.e., when there is wet soil underneath the floor), consider heat loss to the soil underneath the greenhouse

Perimeter Insulation

- At least 1-ft deep (preferably 2 ft)
- At least 1-in. thick (preferably 2 in.)
- Larger numbers can be used for colder locations

- Avoid gaps
- Try to work neatly around post footings
- Can be difficult as retrofit

Side Wall Insulation (while still allowing light through)

Effect of Wind Velocity and ΔT ($T_{inside} - T_{outside, 99\%}$)

- If $\Delta T > 70°F$ (difference between inside and outside design temperature), and/or if average wind speed > 15 mph:

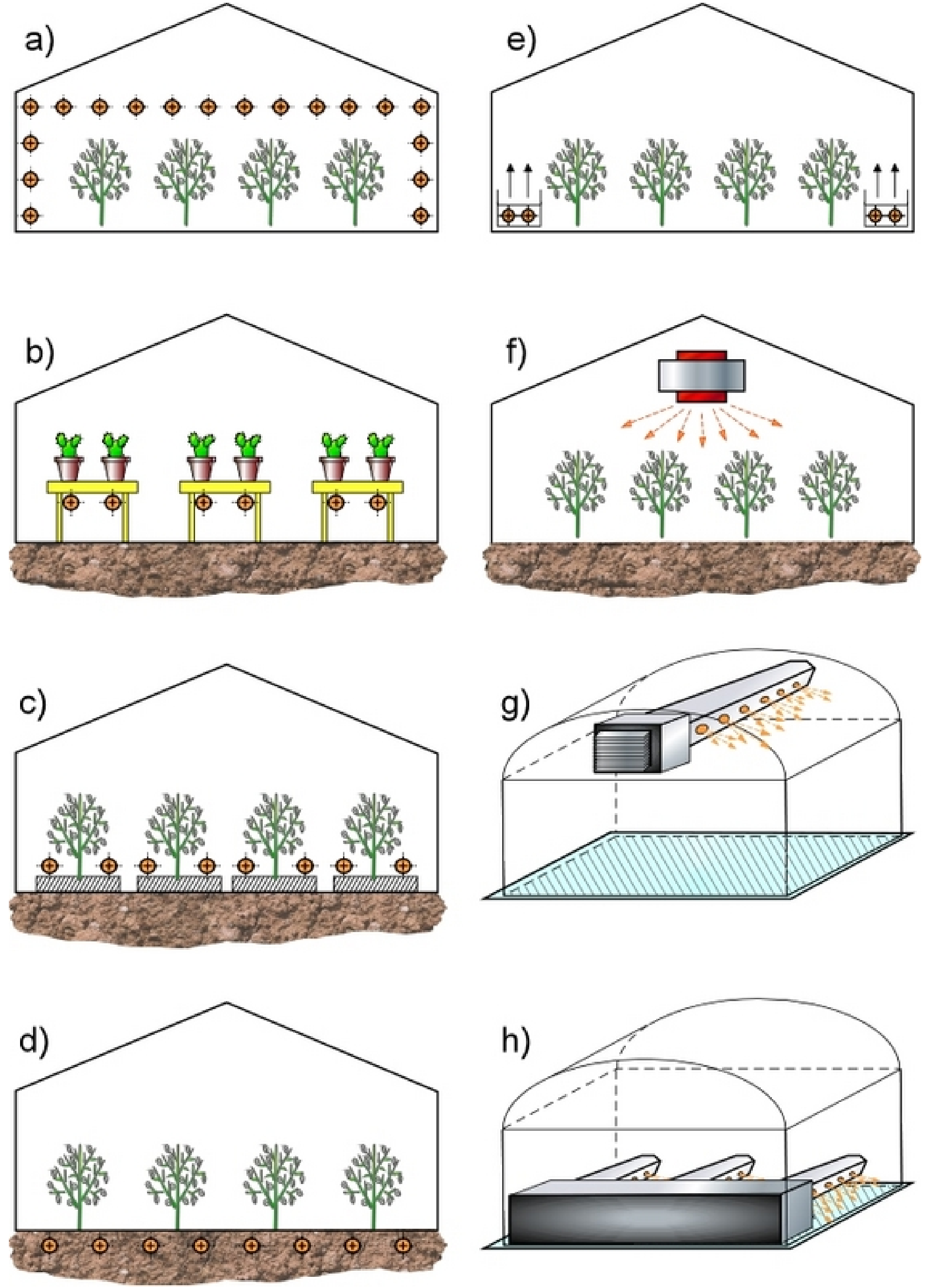
  Multiply the calculated heating requirement by:

  - (1 + 0.08) for every increase in ΔT of 5°F
  - (1 + 0.04) for every 5 mph increase in speed

For example, if $\Delta T = 80°F$ (1.16) and the average wind velocity is 25 mph (1.08): multiply the calculated heating requirement by a factor of: 1 + (0.16 + 0.08) = 1.24

Common Greenhouse Hot Water and Air Distribution System Designs

a) Overhead and perimeter pipes
b) Bench heating
c) Intracanopy heating pipes
d) Floor heating
e) Perimeter heating
f) Overhead unit heater
   (often installed at end walls)
g) Overhead polytube distribution
h) On floor polytube distribution
   (often installed underneath benches)



Source: http://www.iga.1it.pl

Heating with Hot Air or Hot Water

- Hot water is preferred over hot air
  - Improved uniformity
  - Flexibility of delivery (floor, bench, air, pre-heating)
- Hot air systems are cheaper to install
- Hot water systems require water treatment
- Root zone heating (floor and bench heating):
  - Uniform heat (typical range: 15-25 Btu/hr per ft^2)
  - Heat close to the crop (lower air temperature?)
  - Floor heating: acts as buffer in case of system failure
  - However, requires additional heat supply (because the root zone water loop temperature is typically kept between 90 and 110°F to prevent root damage)

Root Zone Heating

- In the floor

- Heated ebb and flood floor

- On the bench

Radiant (Infrared) Heating?

- Only heats surfaces ‘in view of’ radiator
- Allows for lower air temperatures
- After absorption, heat is dissipated by re-radiation and convection
- As a result, potential uneven canopy heating
- Mounting at appropriate distance above the crop canopy can be a challenge
- Quick response time

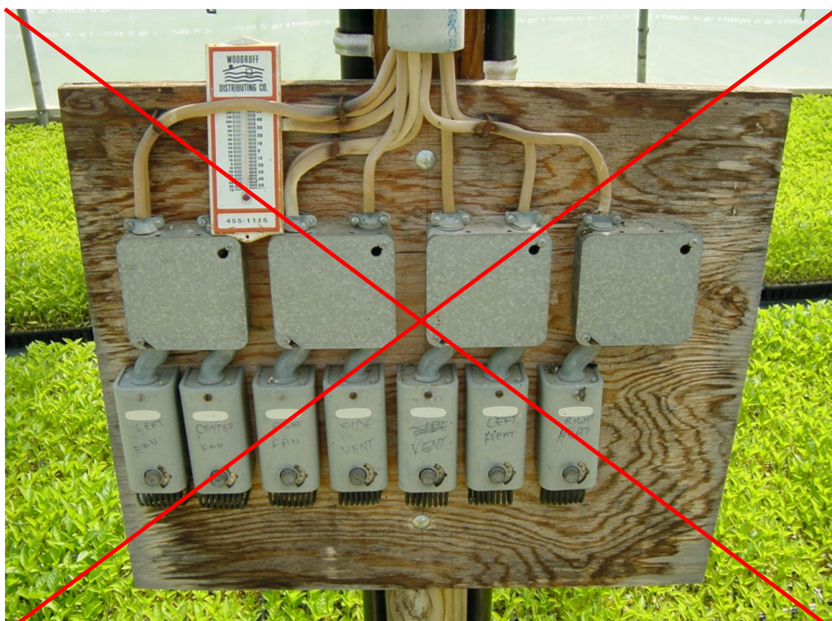
Energy (and Shade) Curtain

Heat Storage (insulated water tank)

Can be used to optimize the efficiency of a heating system

Proper Control

- Use a reliable temperature sensor (e.g., RTD)
- Put the sensor inside an aspirated box (protected from sunlight and moisture)
- Locate sensor near the plant canopy
- Place sensor at a representative location



Comparing Energy Prices (national averages)

Fuel	unit	$/unit	Btu/unit	$/MBtu	Typical η (%)*	$/Mbtu
Electricity	kWh	0.125	3,412	36.64	98	37.38
Oil (#2)	gal	2.60	138,690	18.75	78	24.03
Natural gas	therm	1.12	100,000	11.20	82	13.66
Propane	gal	2.70	91,333	29.56	78	37.90
Kerosene	gal	3.15	135,000	23.33	80	29.17
Coal (anthracite)	ton	200	25,000,000	8.00	75	10.67
Wood	cord	200	22,000,000	9.09	63	14.43
Wood pellets	ton	250	16,500,000	15.15	78	19.43
Corn	ton	200	14,000,000	14.29	78	18.32

*steady state efficiencies, seasonal efficiencies are lower (they take into account e.g., heat losses when the heater/boiler is off and losses due to a continuous pilot light). Some manufacturers offer heating system models with higher conversion efficiencies.

Source: U.S. Energy Information Administration (1/2015)

Reducing Energy Costs
(note: savings can not be summed)

- Always start with conservation measures!
- Use an energy/shade curtain (30%)
- Avoid unintended cracks/openings (2-10%)
- Consider high efficiency heaters/boilers (20-40%)
- Consider condensing boilers (10-20%)
- Perform timely maintenance (5-10%)
- Use computer control and variable speed motors and pumps (5-10%)
- Lower heating system temperature (5-10%)
- Use highest R-value for insulation (5-10%)
- New installations: consider co-generation (50%)

Summary

- Maximum required heating capacity can be calculated based on location and greenhouse construction characteristics
- Different heating system options (hot air or water) are available (carefully evaluate pros and cons)
- When selecting a fuel source, consider unit price, energy content and conversion efficiency
- Delivering heat near the crop (e.g., floor heating) can allow for lower air temperatures (savings)
- Use (frequently) calibrated and shielded sensors placed in appropriate locations (near plant canopy)

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Questions?